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Modulating Retroreflector Architecture using Multiple Quantum Wells for Free Space Optical Communications

By

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ABSTRACT

In this paper, we describe a demonstration using a Multiple Quantum Well modulator combined with an optical retroreflector which supported a high speed free space optical data link. Video images were transmitted over an 859 nanometer link at a rate of 460 kilo bits per second, where rate of modulation was limited by demonstration hardware, not the modulator. Reflection architectures for the modulator were used although transmission architectures have also been investigated but are not discussed in this paper. The modulator was a $GaAs/Al_{0.3}Ga_{0.7}As$ quantum well which was designed and fabricated for use as a shutter at the Naval Research Laboratory. We believe these are the first results reported demonstrating a high speed free space optical data link using multiple quantum well shutters combined with retroreflectors for viable free space optical communications.

I. INTRODUCTION

A means to produce high speed optical communications in free space using methods which are compact, have low mass, low power, and are suitable for spaceborne and airborne missions is one of growing interest to the aerospace community. Combining modulators with optical retroreflectors is an idea which has been recommended for some years which would support such a goal. A successful experiment using Ferro Liquid Crystal (FLC) devices was recently done over a free space link at a rate of 1200 bits per second [1]. Practicable communications links, however, demand data rates on the order of Megabits per second (Mbps) and higher. To achieve such data rates, the use of Multiple Quantum Well (MQW) devices configured in transmissive or reflective architectures with optical retroreflectors is recommended [2,3]. A method is demonstrated which couples MQW technology with optical retroreflectors of relatively large apertures (1/2 cm to 1 cm in diameter) which can support data rates of Mbps and higher while consuming less than one watt of onboard power.

A modulating retroreflector or array obviates the necessity to fly a laser and telescope for cases where optical communications are desirable. Advantages of optical frequencies over radio frequencies (rf) include compactness, low probability of intercept, low power, and relief from crowded frequency bands. The modulating retroreflector approach, in particular, can be configured to negate the need to fly an antenna or gimbaled telescope system. The MQW device specifically is more robust, has lower drive powers, is inherently significantly faster, and is not subject to polarization unlike other shutter materials and methods.

In this demonstration, we show the viability of such a device and demonstrate optical communications on the order of 500 kilo bits per second (kbps) limited by the computer overhead, not the device itself. We believe these are the first such results using a multiple quantum well shutter with a retroreflector for a viable optical communications link for ground-to-space, space-to-space, ground-to-air, or air-to -space applications.

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II. THE CONCEPT

The modulating refreflector device could be configured to fly on a spacecraft or airborne platform. A digitized signal obtained from the onboard system would be matched to drive the modulator which can be configured in a reflection or transmission geometry with an optical retroreflector or a retroreflector array. An array typically consists of a number of devices configured in a manner to optimize return over the largest interrogation arc from the ground or mother platform [4]. A retroreflector array with MQW modulators coupled to all or some of the retroreflectors has two advantages: First, an array of devices means that the area per device can be kept small. Since the modulator's speed is Resistor-Capacitor (RC)-limited, higher speed can be maintained. Second, an array can open up the onboard Field-of-View (FOV) to maximize downlink time to the collection site.

The platform would be interrogated from the ground or interrogation platform using a laser system. The modulating retro reflector would then return the light along the path of incidence characteristic of a retroreflector but modulated, for example by On Off Keying, as the platform moves through the FOV of the interrogator site. A concept of operations for ground-to -space is illustrated in Figure 1 although a space-to-space configuration would be similar.

III. MULTIPLE QUANTUM WELL MODULATORS

Multiple Quantum Well optical modulators are all solid state semiconductor devices. They are grown by Molecular Beam Epitaxy or Metal Oxide Chemical Vapor Deposition. These growth techniques allow layers as thin as a single atomic layer to be deposited over areas of 10 cm^2 or more. By depositing alternating layers of semiconducting material, the optical properties of the bulk material can be modified.

With appropriate choice of materials MQW modulators can be designed with operating wavelengths from 0.8 μm to 1.55 μm. Typical MQW modulators are made of materials such as gallium arsenide. The active part of the modulator is a few microns thick. The total thickness of the device, including the substrate, is about half a millimeter. Figure 2 illustrates typical device dimensions.

Through design, a large absorption band can be created at the desired wavelength. A modest voltage (<20V) applied across the sample will strongly alter the absorption. As a result, the transmission of the device for light at the design wavelength can be changed electronically. The shift in absorption is illustrated in Figure 3 for the device used in the demonstration.

Unlike other optical modulators, such as FLC devices whose maximum speed is limited by the intrinsic switching time of the material, MQW modulators are limited only by RC charging times, and can support up to rates of tens of Gigahertz (GHz), depending on the active area. They also consume a small amount of power and are mechanically robust. The specifics in terms of speed and drive voltages are driven by aperture requirements. Large device apertures, on the order of 1/2 cm to a cm, are desirable for long range applications such as the space-based or airborne configurations which this demonstration supports. Power requirements are estimated to be on the order of less a half watt per device for these dimensions.

IV. EXPERIMENTS AND DEMONSTRATION

Experiments were conducted using MQW devices that were both transmissive and reflective. The MQW device used in the demonstration was a reflective device, specifically grown as a $GaAs/Al_{0.3}Ga_{0.7}As$ MQW, cleaved 5 mm on a side. The incident interrogating light is reflected from the MQW modulator onto the retroreflector and back. Modulation of this device was optimized at 859 nm and configured to produce a 5:1 contrast ratio overall.

The laser source used for these experiments was a 150 mW diode laser which was temperature-tuned to 859 nm for compatibility with the MQW modulator. The single spatial mode output beam had a 3:1 aspect ratio and was collimated and circularized with a lens and an anamorphic prism pair, which produced a 1 cm diameter beam. Most of the energy was directed to a beam dump after reflection from a 1000:1 beamsplitter. The system was typically operated so that only about 5 μw of laser power was incident on the modulator.

The modulating retro system was located approximately 17 m from the source and detector. The modulator was driven by a 6.5 V pulse train from a video camera, the analog output of which had been digitized using a frame grabber board in a computer running

LabView. The data consisted of image information captured with 4 bit gray scale in a 160x120 pixel field. The interrogating continuous wave diode laser beam was reflected from the modulator and returned along its original path passing a second time through the modulator . The receiver computer could recover the data from the modulator at 2.3 frames per second (fps).

At the beamsplitter on the receive portion of the bench, most of the light was directed to the avalanche photodiode through a collection lens. The signal, now converted to voltage, was further amplified and processed before being displayed as a video image. Figure 4 is a block diagram of the bench configuration.

Gray scale video was transmitted across the optical link using a modified RS-232 protocol with suspended hand shaking. Two 166 MHz Pentium computers were used. Although they added computer overhead and slowed frame recovery rates, they enabled user-friendly reconfigurability. One was used to digitize the analog video signal and send the pulse stream to the driver electronics for the modulator which was modulated at a rate of 460.8 kbps. The other displayed the converted the amplified transmitted signal as a digitized video image. A block diagram of the transmit/receive system is shown in Figure 5.

The modulator driver circuit converted the RS-232 data output from the image-acquisition computer into the voltage and impedance levels required to drive the modulator. In addition, the drive voltage levels applied to the modulator were designed to be adjustable, so that the operation of the modulator could be optimized. A convenient feature of this circuit is that the voltage levels applied to the modulator can be changed simply by adjusting the power supply voltages. Maximum overall power required to drive the device was 50 mW.

V. RESULTS

A data rate of 460 kbps was supported by the reflective MQW modulator with a maximum power draw of 50 mW. The pulse train recovered in the NRL MQW retroreflector system is shown in Figure 6. From this figure, it can be seen that the digitized data stream from the video image was converted and transmitted with integrity on the carrier beam. In order to ease reconfigurability, computer interfaces were used at the transmit and receive ends, introducing substantial overhead to the frame recovery rates. The MQW device itself was able to support higher than 600 kbps rates in separate pulse train measurements. Frame rates of 2.3 fps were achieved, indicating that programming overhead reduced rates by over 50% from the continuous-streaming rate of 5.3 frames/second.

VI. SUMMARY

We have demonstrated the viability of a high speed optical data link for free space optical communications using a large aperture multiple quantum well device coupled with an optical retroreflector. The MQW device architecture reported was reflective but experiments were also done with transmissive MQW modulators combined with retroreflectors. Future work will include investigating additional quantum well architectures to increase modulator response and investigating coupling the MQW shutters with with retroarray architectures to open up the field-of-view while keeping the individual apertures small enough to maintain data rates of Mbps and higher.

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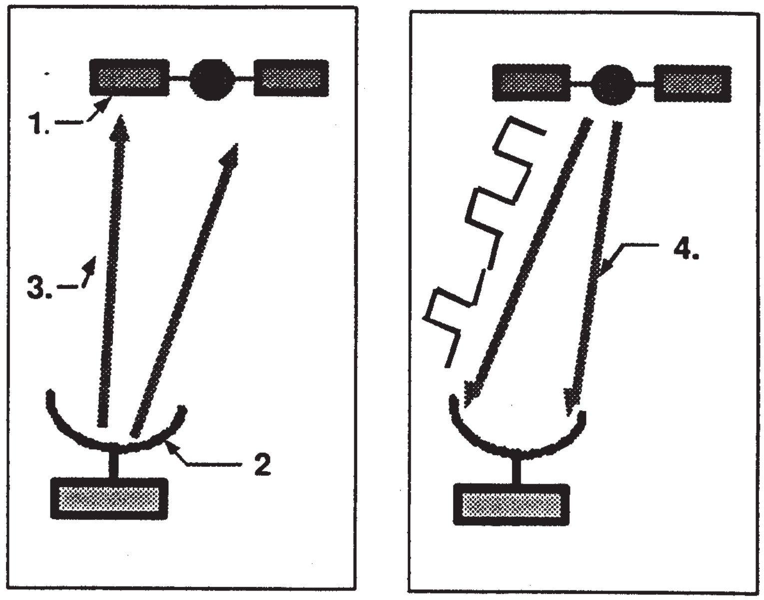

Figure 1. Concept of Operations for Ground-to-Space Optical Communications using a Modulating Retroreflector Array: (1) Satellite; (2) Transmitter/Receiver; (3) Interrogation Beam; (4) Modulated Beam.

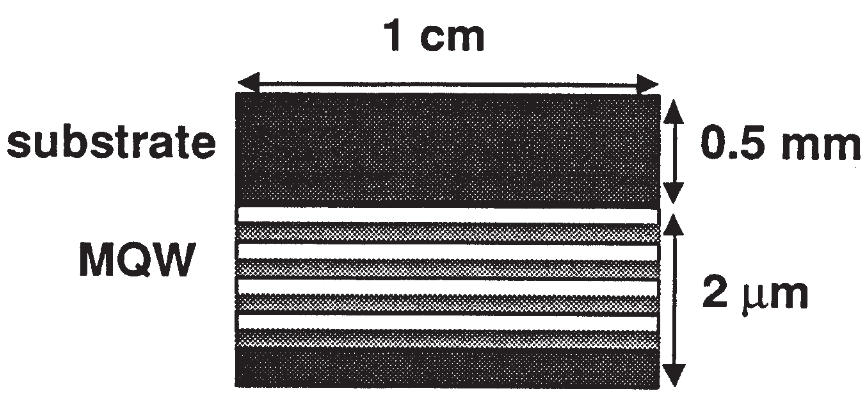

Figure 2. Multiple Quantum Well Modulator Dimensions.

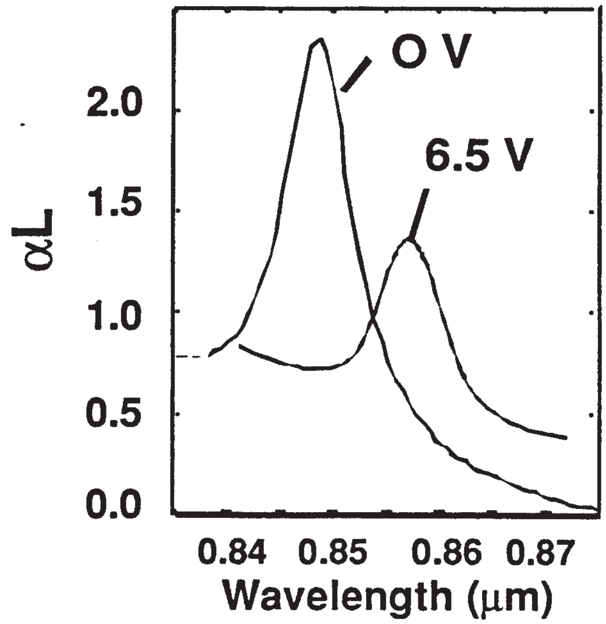

Figure 3. Absorption of a quantum well modulator at two different applied voltages. Note shift in absorption enables On-Off Keying.

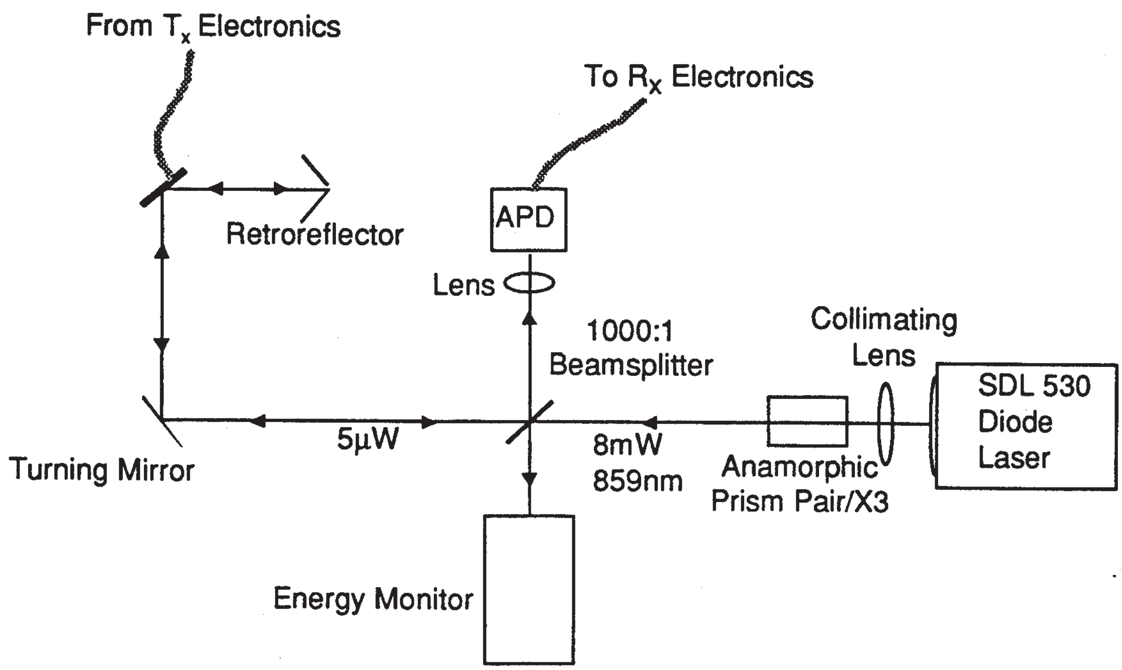

Figure 4. Bench Configuration for Demonstration

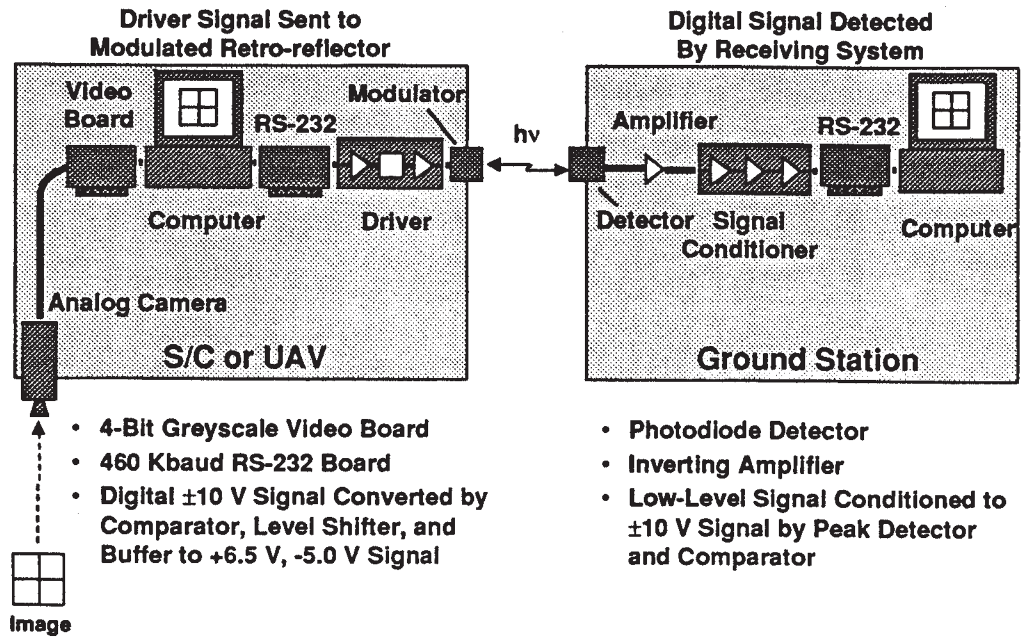

Figure 5. Transmitter/Receive Video Configuration.

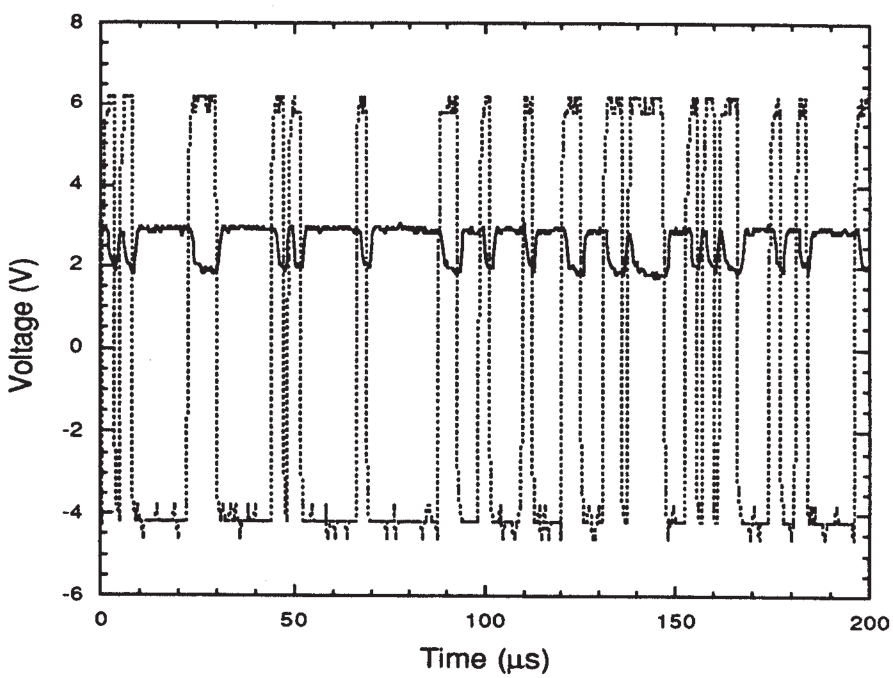

Figure 6. Driver Voltage and APD Output of Received Signal. The dashed line is the driver voltage to the MQW. The solid line represents the avalanche photodiode output before amplification and signal configuration.